CNES PROTEUS/MYRIADE : TWO LOW COST SMALL SATELLITE FAMILIES. PRESENTATION OF THE GROUND SEGMENT AND THE OPERATIONS

Paul Gélie
CNES - Centre Spatial de Toulouse
DEE/EO/ETM/M2
18 avenue Edouard Belin
31401 Toulouse Cedex 9
paul.gelie@cnes.fr

Philippe Crebassol
CNES - Centre Spatial de Toulouse
DEE/EO/ETM/M2
18 avenue Edouard Belin
31401 Toulouse Cedex 9
philippe.crebassol@cnes.fr

ABSTRACT

PROTEUS (mini satellites) and MYRIADE (micro satellites) CNES satellite families are two examples of product lines with global cost reduction objectives. We focus here on the command control ground segment and operations aspects. On the ground segment hand, cost reduction has been mainly obtained by a modular architecture based on very simple principles, by the multi-mission capability and by the high level of community between the two satellite families. On the operations hand, cost reduction has been mainly obtained by an adequate spacecraft conception, many automatic functions in the ground segment and also by the community between all the satellites. All is of course based on a highly integrated design between ground and board.

1 - INTRODUCTION

We describe here how with a global design, involving the spacecraft, the ground segment and the operations, it has been possible to build low cost ground means and operations for CNES mini and microsatellites. This integrated approach has lead to a clear sharing of responsibilities among the sub-systems, thus allowing to simplify the conception of each of them. This is shown through a brief ground segment presentation followed by a cost savings factors list for the ground segment development. Then, the operations concepts are presented, to show how additional cost reductions have been obtained in this field.

2 - GROUND SEGMENT PRESENTATION

2.1 - ARCHITECTURE PRINCIPLES

The ground segment architecture concept presented here, was designed about 6 years ago for the PROTEUS minisatellite product line purpose. PROTEUS is a package containing a reusable platform for earth observation, telecommunications or scientific uses and its command control ground segment. So each mission mainly consists in adapting a payload on the existing platform and defining

interfaces between the existing command control ground segment and the mission specific ground segment.

The ground segment has a very simple architecture, with three elements :

- ❖ An S-band earth terminal called TTCET.

- ❖ A command control center (CCC).

- ❖ A data communication network (DCN).

The TTCET is unmanned. It is monitored from the CCC like a spacecraft : it has a command and control interface which is CCSDS like, with remote monitoring packets sent to the CCC and remote commands sent from the CCC.

The command control center has a modular architecture. Each function is assigned to a dedicated software component, which is generally installed on a dedicated computer. Most of the software are COTS (in particular the real time functions, developed by Alcatel Space Industries for telecommunication satellites) or existing CNES software that has been adapted to the context. Main software components and functions are shown in the following table :

Component	Function
G1	TM/TC (real time functions)
G2	Space mechanics computations
G3	Archiving and trend analysis (differed time functions)
G4	External exchanges
DRPPC	TM visualization (mimics)
SWWW	Web server to access CCC data base
Agenda	Automatic scheduling of CCC tasks
Sygale	Automatic call of operator in case of red flag

The CCC is able to be interfaced with CNES multi-missions means (mainly an S-band stations network and an orbit computation center). This allows to have an exceptional support of several stations during the LEOP phase or at any time during the satellite lifetime, in case of contingency. This increases the number of passes along the day and provide ranging measurements.

Several technical choices have lead to simplify the ground segment.

Communication :

All the exchanges are based on IP protocols. TCP/IP is used for real time exchanges and FTP for file exchanges. Most of the exchanges are file transfers.

Network architecture is based on standard elements like routers, in order to minimize any WAN changes on the CCC or TTCET software.

TTCET conception :

The TTCET sends only part of the telemetry in real time during a satellite fly-by. The other part is stored in files on the TTCET which acts like a server with poor intelligence. Clients can connect when they need to retrieve their data.

The TTCET is managed in open loop through ephemeris files, to avoid the need of complex equipment inside.

Telecommand emission :

Telecommand generation is shared between mission center and CCC, with a clear separation. Mission center is responsible for the payload commands, CCC is responsible for the platform commands. CCC does not check the consistency of the telecommand files it receives from the mission center with the satellite current state (only the basic syntax is checked).

COP1 protocol from CCSDS is used. Its management is centralized at CCC level.

Hardware :

Most of the software components run on regular PCs (except G3 and SWWW run on work-stations).

This ground segment is used for the first PROTEUS mission, JASON1, launched in December 2001.

But this concept had one limit in cost saving, because the ground segment was to be duplicated for each new mission, thus implying to buy new hardware but also to buy one TTCET for each satellite.

So, when the microsatellite family was decided with even stronger cost reduction objectives, it was first decided that its design would be based on the minisatellite family design, in order to take benefit from all the already done work, and secondly that this design should be improved from the cost reduction point of view.

From the spacecraft on-board point of view, the strategy was slightly different from PROTEUS in the way that the MYRIADE platform basis can be adapted by choosing the elements among a list of COTS, according to the mission particularities (for instance some mission will need propulsion and others not, some will have a GPS and others not).

On the ground segment hand, it has mainly consisted into adding a multi-satellite and multi-mission capability, and improving automation.

This means first that the control center has evolved towards a single CCC to command and control several microsatellites belonging to different missions. The CCC is thus tailored to welcome up to 7 satellites from 5 different missions. This has needed a few adaptations of some of the software, but the concept remains exactly the same with the same functions on the same components. This also means that instead of having one TTCET per satellite, we will have a reduced number of TTCET organized in network, and shared by the various satellites.

The automation improvement consists in the possibility to send telecommands without operator, which was also a software adaptation.

At this step, PROTEUS family was still with its mono-mission concept and microsatellite family was with a more ambitious multi-satellite, multi-mission concept.

So finally, it was decided to also have a multi-satellite, multi-mission ground segment with automatic TC sending capability for the next PROTEUS missions. The final step thus consists in taking benefit of the work done for the microsatellites in order to have similar ground segments for both families.

The final architecture is to have a shared TTCET network used both by the minisatellites and microsatellites. At date, it consists in two TTCETs which will be shared by 5 or 6 satellites. Linked to this network are two CCC : one for the PROTEUS family and one for the MYRIADE family. Most of the data communication network is therefore common between the two families.

The ultimate step would be to integrate the JASON1 operations into the new multi-satellites PROTEUS ground segment.

It must be noted that all this has been possible because most concepts are similar between the two satellite families, notably the on-board to ground interface.

2.2 - ARCHITECTURE ANALYSIS FROM THE COST SAVINGS POINT OF VIEW

2.2.1 - DEVELOPMENT COST SAVINGS

Considering the initial concept imagined for PROTEUS and presented above, we see that the cost saving was first due to the possibility to reuse the spacecraft platform and the ground segment for several different mission. This implies that the development cost is maximum for the first mission. The development of the following missions represents only a delta for specific aspects, but the fundamentals are not modified.

Then it must be noted that the whole command control ground segment contains few elements (only three). It must also be noticed that only one station is needed, due to the on-board conception. This an important point for cost reduction.

The TTCET conception itself was designed as to reduce cost, as it is unmanned (which impacts mainly on operations costs) and as it is a small station with very simple functions inside. It is driven by ephemeris files (no auto-track is available for example). Orbit computation is based on GPS fixes sent in the satellite telemetry, thus TTCET has no ranging function. TTCET is conceived as a telemetry data server, to which clients connect according to their needs, so there is no complicated data delivery function.

Another cost saving was obtained through the reuse of exiting software that was simply adapted for PROTEUS needs.

The CCC architecture is very modular, with functions clearly spread out among various components, with clear responsibilities for each of them and with simple interfaces between them (file transfers). This notably simplifies the software. The CCC interface with CNES existing operational means is also a cost reduction factor, as the equivalent functions were not developed twice.

The various technical choices presented above have of course contributed to cost reduction. We can recall here for instance the telecommand emission protocol which is a standardized CCSDS protocol, thus enabling the use of existing tool. From the commanding point of view, another important point is the command responsibility delegation to various entity (mission center for the payload, CCC for the platform), thus allowing to limit the complexity of the controls inside the CCC.

The extensive use of PCs was also somewhat new at CNES where the use was to have only workstations. This is an important cost reduction factor.

If we now look at the second step which was the achievement of the microsatellite ground segment, we see that immediate cost reduction is obtained by reusing the PROTEUS ground segment. The architecture is strictly the same, and the software components are the same. Of course they had to be slightly adapted to cope with a few on-board to ground particularities. But this was very poor compared to the initial development investment. At this point, the ground segment cost was already well reduced.

But thinking about the future and taking into account the increasing number of missions, it was obvious that something more was possible to reduce costs in the next years. That is why an additional investment was decided, to add multi-satellite and multi-mission commanding capabilities to the ground segment. This will help reduce cost by limiting the hardware to buy for the CCC, limiting the space occupied by the CCC, limiting the number of TTCET needed.

Now, considering that the basis for operations was to have operators only during working hours and working days, and considering the increasing number of satellites along the years, it was necessary to have a little more automation in the control center. So the automatic TC sending was decided.

Next step simply consists in taking benefit of all those improvements for the next PROTEUS satellites, thus improving the cost reduction for this family by leaving the duplication of a mono-mission ground segment for a multi-satellites ground segment.

Last step will be to integrate JASON1 CCC in the multi-satellite PROTEUS CCC. This would prevent from maintaining the former PROTEUS ground segment in addition to the multi-missions one, and so to reduce costs.

2.2.2 - MISSION TO MISSION COST SAVINGS

After the initial development, comes the operation phase, during which new missions must be regularly added inside the ground segment.

In this phase, CCC cost reduction is obtained first because most of the components need no adaptation at all for the next missions. Only added PCs may be required. Only the

G2 and G4 (space dynamics and external exchanges) are mission specific. But those two components are derived from the same kernel, which reduces costs. Finally, development for a new mission is reduced to a specific G2 and a specific G4.

Concerning the hardware, it is not always necessary to add some computers. This is because several G2 software can run on the same machine. It is the same for G4. In addition, one G3 computer can welcome several missions. We do not need as many G1computer as satellites, but only as many as simultaneous passes over the different earth terminals. Only one SWWW, one agenda and one Sygale are necessary. And finally DRPPC number is linked to the G1 number and most of them are shared between the missions.

Concerning the TTCET, there is a dedicated project at CNES, in charge of tailoring the network. We have shown that installing two TTCETs, plus using existing CNES stations should be enough for the coming seven years. So the investment is made and nothing should have to be done for the following missions at least for the next seven years.

So concerning the development for a new mission, we see that the multi-satellites architecture reduces it to the minimum, because most of the resources are shared.

3 - OPERATIONS PRESENTATION

This highly automated control center was very promising.

When sizing the staff required for spacecraft operations, the same question always raises : how can we have a tightly staffed operational team, sufficient for the nominal routine activities, who can also face any severe anomaly possibly requiring H24 operations?

The first cost reducing axis deals with the preparation and qualification of the operations, before launch : the operations team is involved as soon as the very first test between the control center and the satellite simulator; there is no "qualification by the project team", and then a hand-over to an "operational qualification". The ops team is in charge of the satellite operations as soon as the beginning of the now so called "qualification phase", under supervision and expertise by the project team.

The second axis is to alleviate the work load by getting rid off any "not proved as necessary" activity. This is fairly difficult, as we have to face different habits and cultures. For instance : at a time, it was anticipated to dump the on-board telecommand buffer after a TC upload to check the TC was actually inside the buffer. Why not? But was it really necessary? After analyze, it appeared that the COP1 protocol ensures the correct transmission to the satellite,

and there was no case of failure where the satellite receiver gets a TC and does not transmit it to the spacecraft processor module. There was also no case of failure where the on board software gets the TC and does not transmit it to the addressed application. As "not proved as necessary", this dump request was abandoned.

Third axis was to decrease the number of cases where a quick reaction is required, the so-called "red flags". Basically, the only red flag is a satellite safe mode. This mode is steady, but it was required that the operational team comes over at the control center to check it is actually steady (we don't want to loose the bird!!).

Fourth axis was to reduce as far as possible the training of the staff, but still keeping it current. A large proficiency test is in place, carried out every 3 months, on three days, and covering all the typical anomaly cases we might have to face : safe mode of course, but also payload failure recovery, gyros swap, on board software upload, etc.

Fifth axis was to share the staff with other space programs, such as SPOT (earth remote sensing CNES program). As the SPOT control center is in the same premises than the PROTEUS and MYRIADE control centers, that was more than doable.

3.1 - JASON : THE FIRST EXPERIENCE

The first space program using this new concept is JASON, an altimetry mission in partnership between CNES and NASA. The satellite was launched in December 2001.

Apart its own altimetry mission, one of this aim of this first in flight experience was to demonstrate our new concept is adequate and fulfills its promises.

The whole operations was sized the following way :

- A so called "Jason1 space component ops manager" full time position, counterpart of the mission centers managers, and supervising all the control center and satellite activities,

- A so called "Jason1 ops controller" mid time position to check on an every day base the adequate functioning of the control center.

- Added to these positions, a part-time satellite manager position is in charge of the satellite surveillance and expertise.

- part-time satellite support : 3 engineers, kept current

- part-time ground software manager position, aimed at accepting any new version of software and in charge of the contracts with the software industrial companies,

- ground segment support, part time

Of course, this first satellite of this new product line had to face difficulties, mainly in the satellite building and in the simulator development process. The launch was delayed several times, but the ops team was all the time kept as it, thus increasing the global cost in the development phase.

After launch, the spacecraft appeared to behave as expected, and even much better regarding its performance, but degradations on the star tracker led to an expertise charge and unanticipated surveillance operations. Finally, we had to develop a new version of the ground software to make up for the star tracker degradation.

At last, the flight dynamics process was not as automated as anticipated. Therefore, we had to implement a new software version.

But all this is now through, and nowadays, the work load tends to be as the ideal one.

3.2 – PROTEUS : MISSION TO MISSION COST SAVINGS

The second satellite of the PROTEUS product line is CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations), part of the NASA Aqua train.

The satellite is planned to be launched in late 2004.

Presently, operations speaking, the process is well on the path and no particular problem is anticipated. Part of the ops team started to work on CALIPSO in June 2003, as planned.

Other programs are under development : COROT (French exoplanets observation program, launch in late 2005), SMOS (ESA humidity and saltiness observation program, launch in early 2007), JASON2, the JASON1 follow on.

At first sight, we might think that the overall number of people involved in the Proteus line does not increase when a new mission is added. For instance, the ops manager in charge of JASON1 and CALIPSO (half time for each), might assume JASON1, CALIPSO, and COROT (third time each).

This is only partly true, and the sharing has limits. Our goal is of course to keep a tightly staffed team, without any

significant increase when adding a new mission, but at date we cannot say for sure that operating 3 satellites will require the same staff than single satellite activities. The main problem being not to operate a 3 satellites control center and 3 satellites in flight, but to face 3 different mission counterparts : difficult to make a program project manager aware he's not alone and must accept some priorities rules, leading to the fact he has not an ops team 100% at disposal.

The following board shows how we anticipate the cost savings :

personnel	Jason1, first 18 months	Jason1 today	Jason1 + Calipso	Jason1, Calipso, Corot
Space component ops manager	80%	50%	80%	160%
Ops controller	50%	50%	100%	100%
Satellite manager	100%	50%	100%	100%
Satellite supports (3 people)	2*100% + 20%	50% + 2*20%	In routine : 3*20%	In routine : 3*20%
Ground segment manager	100%	50%	50%	25%
Ground segment support	50%	25%	25%	25%
total	**6**	**3,1**	**4,1**	**4,7**
Ratio staff/number of SLs	**6**	**3,1**	**2**	**1,6**

3.3 – FROM PROTEUS TO…

The programs which are part of the MYRIADE product line take of course a huge advantage of the JASON1 heritage and the way we anticipate the operations on CALIPSO and further spacecrafts. One of the lessons learned is probably to put in place for the first months of the first satellite of a new product line an oversized team, and decrease it after.

CNES is also involved in several A phases based on Proteus and Myriade, both French and international, providing a ground segment and operations. The prices of our proposal appear to be very competitive.

CONCLUSION

Cost reduction was successful on mini and microsatellites, even if a few original objectives were not totally reached.

Key words to succeed on those projects were :

- ❖ Integrated design between on-board and ground parts of the system,

- ❖ Extensive reuse of existing components with slight adaptations,

- ❖ Basic architecture principles,

- ❖ Automation to allow staffing reduction,

- ❖ Share of the ops staff between several missions,

- ❖ Ops work load limited to the "strict necessary".

Nevertheless, two main drawbacks have been identified :

- ❖ First it is not so easy to manage several missions developments in parallel (for instance because each mission generally needs slight software adaptations on common source code, with concurrent schedule).

- ❖ Secondly, it is sometime difficult to urge the new missions to cope with the existing system.

But this is finally poor compared to the general benefit obtained.

_____